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# Results of a Monitoring Study of the Littoral and Planktonic Assemblages of Aquatic Invertebrates in Lake Davis, Plumas County, California, Following a Rotenone Treatment

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**Abstract**

Zooplankton and littoral macroinvertebrate communities were monitored as part of a 1997 rotenone treatment of Lake Davis, Plumas County, California. Samples were taken pre- and post-treatment, starting in July, 1997, and ending in August, 1999. Changes in zooplankton taxa richness during the study could not be distinguished from natural yearly cycles of increase and decrease. Overall zooplankton abundance decreased significantly immediately after the treatment, recovered to roughly 300% of the pre-treatment abundance within 1 year after the treatment, and was at approximately 150% of the pre-treatment abundance 2 years after the treatment. Littoral macroinvertebrate taxa richness decreased immediately after the treatment, then increased significantly over the next 2 years as additional taxa were found in the reservoir after removal of the fish community. Two sensitive macroinvertebrate taxa that were sampled prior to the treatment were not found in the samples taken over the 2 years after the treatment. Littoral macroinvertebrate abundance decreased to approximately 57% of the pre-treatment abundance immediately after the treatment, increased to 58% of the pre-treatment abundance within 1 year after the treatment, and was at 61% of the pre-treatment abundance by the end of the study, 2 years after the treatment.

## Introduction

Lake Davis is a reservoir in the upper drainage of the Middle Fork Feather River, near the town of Portola in Plumas County. The reservoir was created in 1967 when the 132 foot high Grizzly Valley Dam was built across Big Grizzly Creek, a tributary to the Middle Fork Feather River, as part of the State Water Project. The reservoir holds 84,371 acre feet of water at full volume, with 4,026 surface acres and an average depth of approximately 21 feet. Depth at the dam is 108 feet. The reservoir has a drainage area of approximately 44 square miles, consisting mostly of mountains and mountain valley habitat. The surface elevation at full pool is 5,775 feet (DWR 1989).

When the reservoir was created, it inundated an ancient lake bed, the deep, fine sediments of which provide a fertile substrate for heavy beds of submerged vegetation that have grown throughout the reservoir’s shallow areas (Erman and Delane 1980). Large wet meadows, draining into the reservoir basin through its tributary streams, contribute additional nutrients to the Lake Davis ecosystem. Phytoplankton thrive in the nutrient-rich waters of the reservoir, and are in turn grazed upon by numerous zooplankton. The dense weed beds and rich bottom sediments provide food and shelter for large numbers of aquatic macroinvertebrates. The abundant micro- and macro-invertebrate fauna of Lake Davis have historically provided an excellent food-base for the fish species in the reservoir. Lake Davis has a long-standing reputation with fishermen as a high quality trout fishery, producing many trophy-sized fish.

A threat to that fishery was discovered in 1994 when an angler fishing in the reservoir caught a 14-inch northern pike (*Esox lucius*), a voracious non-native predatory fish. Further investigation by the California Department of Fish and Game (CDFG) led to the capture and identification of several more pike in 1995. The northern pike are believed to have been illegally planted in the Lake Davis. The large, relatively shallow, weedy areas of the reservoir are excellent habitat for northern pike, providing spawning, rearing, and foraging habitat. Northern pike will prey on many kinds of fish, including spiny-rayed species such as sunfish and bass, but prefer soft-rayed species like trout, suckers, and minnows. It is believed that the pike, which can grow to 110 cm (Fork Length) and 14.2 kg, and can swallow fish up to ½ their body size, will decimate the trout population in Lake Davis, destroying the fishery and damaging the local economy.

Also of serious concern is the possibility that the pike may escape, or be illegally moved, from Lake Davis and become established in other waters. Pike could reach the Sacramento-San Joaquin Delta, where they are likely to thrive and could become a major threat to some already declining native fish species, including outmigrating juvenile Chinook salmon and steelhead rainbow trout. This could also threaten the multi-million dollar commercial and sport fisheries based on the various fish species living in and migrating through the Delta.

To prevent a potentially catastrophic expansion of this dangerous invasive species, CDFG decided, after an environmental review process under the California Environmental Quality Act (CEQA), to treat Lake Davis and its drainage basin streams, with rotenone, a plant-derived chemical toxic to gilled aquatic organisms, particularly fish. The reservoir and its surrounding waters would be treated in 1997 to remove all pike and then re-stocked with trout. It was expected that the treatment would also eliminate much of the invertebrate fauna in Lake Davis. A sampling program was developed by the CDFG Aquatic Bioassessment Laboratory (ABL) to monitor changes in the invertebrate composition and abundance in the most important and productive habitats of the lake, from pre-treatment conditions in 1997 to 2-years post-treatment. The primary objective of the sampling program was to obtain an unbiased estimate of the zooplankton and littoral community of aquatic invertebrates before and after the rotenone treatment.

## **Methods**

Invertebrate populations in Lake Davis were sampled prior to the treatment and then monitored for 2 years after the treatment. Sampling site selection was initiated by making a reconnaissance cruise of the reservoir to count all of the shallow coves with good littoral habitat. Most of these coves were located on the shallow, south-west side of the reservoir. The north-east side of the reservoir is much deeper, with steeper bank angles, and lacked littoral habitat. Approximately 20 coves were identified after eliminating coves that were being heavily used for boat or shore fishing. Ten of these coves were then randomly selected for sampling invertebrates. A new set of 10 coves was selected for each sampling period.

Zooplankton were sampled from an anchored boat at the mouth of each selected cove, in the main body of Lake Davis, where the water depth was at least 4.5 meters. A 20.3 cm diameter plankton net with 0.125 mm mesh net and a collection bottle attached at the terminal end was used for the collections. To collect a sample, the net was lowered to the lake bottom and then lifted back up through the water column. The net was dropped and lifted as many as 5 times, depending on the amount of material that was accumulating in the collection bottle at the end of the net. Once a sample was collected, the plankton were transferred to a sample container filled with 70% ethanol and given an identification label. The number of plankton tows and depth of the tow were recorded for the sample and were used, along with the area of the sampling net mouth, to calculate the volume of water filtered for each sample. This procedure was repeated 3 times at the entrance of each of the 10 coves, resulting in a total of 30 samples.

Littoral samples were collected along transects located inside each of the 10 coves where the zooplankton samples were collected. The location of each transect was determined by first dividing the cove into 300 foot (91.4 m) quadrants and randomly choosing quadrants using a random number table. Three transects were chosen and sampled in each of the 10 coves. Transect lines were established perpendicular to the shore, extending from the reservoir margin to the point where the water depth reached 4 feet (1.2 m). Each transect length was recorded since it varied with the bottom topography of the cove. Invertebrates were collected using a “slack net”, a metal-framed, pole-mounted net with a 12 X 18 inch (30.5 X 45.7 cm) rectangular opening and a 2 foot (61 cm) deep bag of 0.5 mm mesh netting. Samples were collected starting at the 4 foot depth and moving to the shore. The slack net was gently bumped along the bottom so that the mud was slightly disturbed, but the attached plants were not ripped up. Upon reaching the shoreline, each sample was cleaned in a plastic bucket, strained in a 0.5 mm mesh sieve, transferred to a sample jar filled with 95% ethanol, and labeled for identification purposes.

Zooplankton samples were collected on 5 occasions and the littoral samples were collected on 4 occasions (Table 1) at the 10 locations. The samples were delivered to the CDFG ABL in Rancho Cordova using chain-of-custody procedures and stored in a walk-in refrigerator until they were processed for taxonomic identification and enumeration. The zooplankton samples were processed at the CDFG Bay-Delta facility in Stockton and the littoral invertebrate samples were processed at the CDFG ABL. For the purposes of estimation of invertebrate composition and abundance, rather than a total inventory of taxa, the raw samples were sub-sampled using standardized procedures (see below). Sub-sampling allowed identifications and counts to be completed in a time- and cost-efficient manner while providing results suitable for bio-monitoring.

**Table 1. Sampling dates for collections of invertebrates in Lake Davis and the time relative to the 1997 rotenone treatment.**

| **Sampling Dates** | **Time Relative to Treatment** | **Zooplankton Sampled** | **Littoral Zone Sampled** |
|---|---|---|---|
| July 22-23, 1997 | 3 months prior | yes | no |
| September 25-26, 1997 | 18 days prior | yes | yes |
| October 21-23, 1997 | 7 days post | yes | yes |
| July 28-30, 1998 | 9 months post | yes | yes |
| August 18, 1999 | 22 months post | yes | yes |

Zooplankton field samples were concentrated in the laboratory by pouring them through a cup screened with 154 µm mesh wire cloth. Water was then added to the concentrated sample to reconstitute a volume with organism densities of 200-400 per ml and that volume recorded. The sample was then stirred to distribute the animals homogenously and a 1 ml sub-sample was extracted with an automatic pipette and placed on a Sedgwick-Rafter cell. All animals were identified and counted under a compound microscope. Additional 1 ml sub-samples were examined until at least 200 animals had been counted. The number per cubic meter for each zooplankton taxon taken in the sampling net was calculated using the following equation:

$$\mathbf{N = (C/V)*(L/S)}$$

Where:

N = the number of organisms per cubic meter
C = the number of a taxon counted in all cells examined
L = the reconstituted sample volume in milliliters
S = the number of Sedgwick-Rafter cells examined (@ 1 ml ea) for organisms
V = the volume of water filtered through the sampling net ($m^3$)

All zooplankton were identified to the lowest practical taxonomic level using Brooks (1957); Donner (1966); Pennak (1991); Ward et al. (1959).

Littoral macroinvertebrate samples jars were retrieved from the ABL Sample Repository, opened and their contents rinsed through a 0.5 mm mesh sieve. The sample contents were then evenly distributed on the bottom of a tray divided into 25 $cm^2$ grids. Macroinvertebrates were separated from benthic material with the aid of a stereomicroscope, one randomly selected grid at a time, and transferred to vials containing 70% ethanol and 3% glycerol. This process was continued until 300 organisms were counted or until all organisms were removed from the tray if it contained fewer than 300 organisms. For subsequent quality control analysis, the material left from the processed grids was transferred into a jar with 70% ethanol and labeled as “remnant”. The remaining (if any) unprocessed sample from the tray was transferred back to the original sample container with 70% ethanol and returned to the ABL Sample Repository.

Abundance of macroinvertebrates in the sample was calculated from the average number of organisms in the counted squares and the total number of squares covered by the entire sample.

All macroinvertebrates were identified to the lowest practical taxonomic level using Baumann et al. (1977); Brown (1972); Edmunds et al. (1976); Merritt and Cummins (1995); Pennak (1991); Stewart and Stark (1993); Surdick (1985); Thorp and Covich (1991), Usinger (1963); Weaver (1988); Wiederholm (1983; 1986); Wiggins (1996); Wold (1974). Organisms in each taxon were saved in individual vials containing 70% ethanol and 5% glycerol and retained as a voucher collection.

Zooplankton and littoral invertebrate taxa and number of organisms were recorded on laboratory benchsheets and the data summaries either hand tabulated or computer generated using Microsoft Excel® spreadsheets and the Systat statistical software package. The following biological metric values were generated for the invertebrate data:

> **Abundance** - an estimate of the total number of invertebrates in the sample. These estimates are calculated from a subsample of organisms.
>
> **Taxa Richness** - the total number of distinct taxa (genera or species) present. Richness is an indication of community diversity in which higher numbers indicate a more diverse benthic community.
>
> **EPT Taxa** - the total number of distinct taxa within the insect Orders Ephemeroptera, Plecoptera and Trichoptera. Insects in these orders tend to be more sensitive to natural and human-induced stressors.
>
> **EPT Index** - the percentage of individuals in the Orders Ephemeroptera, Plecoptera and Trichoptera relative to the total number of individuals in the sample.
>
> **Percent Dominant Taxon** - the proportion of individuals in the most dominant taxon relative to the total number of organisms in the sample. It is an indication of community balance with higher values indicating a stronger environmental disturbance.
>
> **Shannon Diversity Index** (Shannon and Weaver 1963) - an index of community diversity, sometimes interpreted as a measure of the 'health' of a water body. Values generally range between 1.5 and 3.5, increasing with greater species diversity.

## Results

The sampling and taxa identification results, by site, for zooplankton, are reported in Appendix A. The total number of zooplankton taxa identified from all samples taken from the 10 coves during a sampling period, the zooplankton abundance in organisms per liter of reservoir water, and the mean taxa richness for individual samples for the 5 sampling dates are summarized in Table 2. Taxa numbers and abundance of zooplankton (Figure 1) dropped significantly from the July pre-treatment sampling to the September pre-treatment sampling, reflecting seasonal changes in zooplankton populations, with higher numbers expected during mid-summer (July), the most productive time of the year in Lake Davis. The zooplankton abundance declined to less than 0.1 organisms per liter in the samples taken a week after the rotenone treatment, suggesting that the rotenone eliminated the vast majority of zooplankton, although some further natural reduction from population levels from earlier in the year would be expected. By the July 1998 sampling, 9 months after the treatment, the number of taxa had increased, reaching a level of diversity only slightly less than the July 1997 level, while the abundance of zooplanktors had almost tripled in number from that earlier sampling. Zooplankton abundance was still significantly higher in the August 1999 sampling than what was found in July 1997 (pre-treatment), but was approximately half as high as the abundance level in the July 1998 samples.

**Table 2. Total number of zooplankton taxa identified from 10 coves during a sample period, abundance in organisms per liter of reservoir water, and mean taxa richness. October 1997 sampling date was seven days after treatment.**

| | 7/24/1997 | 9/26/1997 | 10/23/1997 | 7/30/1998 | 8/18/1999 |
|---|---|---|---|---|---|
| **Total Taxa** | 17.0 | 12.0 | 10.0 | 16.0 | 15.0 |
| **Ave Zooplankton/liter** | 8.5 | 7.0 | 0.0 | 24.5 | 12.4 |
| **Ave Number Taxa/sample** | 9.7 | 7.3 | 2.4 | 8.9 | 8.4 |

The five most numerous taxa identified during each sampling period are shown in Table 3. Cladocera (unidentified) and the cladoceran genera *Bosmina*, *Daphnia*, and *Diaphanosoma* dominated most of the pre- and post-treatment samplings, along with large numbers of calanoid (*Diaptomus sp.*) and cyclopoid (*Cyclops sp.* and unknown) copepods. A large number of rotifers were collected during the September 1997 pre-treatment sampling, possibly due to a seasonal bloom. Rotifers were among the most numerous taxa in the diminished zooplankton community immediately after the treatment (October 1997), but their numbers in the later samples (July 1998 and August 1999) did not indicate any population surge, as was seen for copepods and cladocerans.

The sampling and taxa identification results, by site, for littoral macroinvertebrates, are reported in Appendix B. Littoral invertebrate mean abundance, taxa richness, EPT taxa, EPT index, % dominant taxon and Shannon diversity for the 4 sampling dates are shown in Table 4. Abundance of littoral invertebrates averaged more than 5000 organisms per sample before the rotenone treatment. Approximately 57% as many organisms were collected per sample one week after the treatment (Figure 2). Abundance per sample then increased slightly in both 1998 (58% of pre-treatment level) and 1999 (61% of pre-treatment level), but never exhibited the rapid increase in abundance observed in the zooplankton, although some individual taxa increased well beyond their pre-treatment levels in the later post-treatment samples (Appendix B). Taxa richness per sample decreased slightly after the treatment, increased significantly the next summer and then

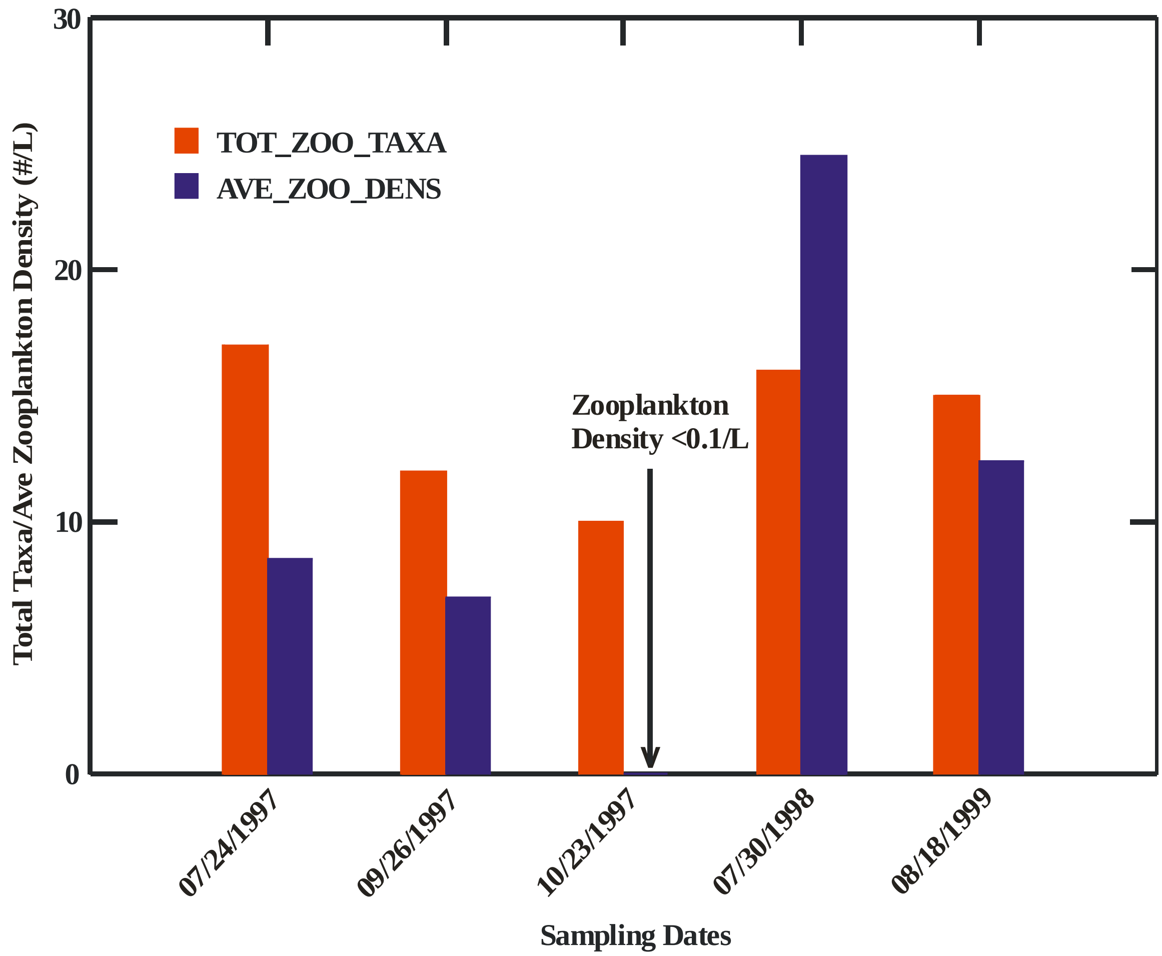


**Figure 1. Total number of zooplankton taxa and average density of zooplankton sampled from 10 coves in Lake Davis.**

decreased to slightly higher than pre-treatment levels by August 1999. EPT taxa averaged 3.9 taxa per sample before the treatment. It decreased to 2.5 after the treatment and stayed close to that level by the last sampling event. The EPT index, the percentage of EPT organisms in each sample, was similar before and immediately after the treatment. It decreased to a low of 4% in July 1998, driven by decreased numbers of the Ephemeroptera genus *Caenis* and increased numbers of several non-EPT taxa. The EPT index increased to a high of 52% in August 1999, as *Caenis* numbers increased and the Ephemeroptera genus *Callibaetis* was captured in much greater numbers. Prior to the rotenone treatment, a single taxon of invertebrate comprised 33% of the each sample, on average(% dominant taxon). This value increased slightly after the treatment, dropped to a low of 26% by July 1998 and increased to where almost half of a sample, on average, was dominated by one taxon of organisms. The Shannon diversity index deceased slightly after the treatment, increased to 2.47 by July 1998 and then decreased to the same average level it was after the treatment.

**Table 3. Five most numerous (shaded) zooplankton taxa identified during each sampling period at Lake Davis. Numbers are totals per sampling event.**

| Taxa | Sample Dates | | | | |
|---|---|---|---|---|---|
| | 7/24/1997 | 9/26/1997 | 10/23/1997 | 7/30/1998 | 8/18/1999 |
| **Copepoda** | | | | | |
| **Calanoida** | | | | | |
| ***Diaptomus sp.*** | 36 | 10 | | 6 | 274 |
| **Cyclopoida** | 214 | 82 | 2 | 1932 | 33 |
| ***Cyclops sp.*** | 157 | 5 | 3 | 419 | 97 |
| **Harpacticoida** | 1 | | 11 | | |
| **other copepodid** | 293 | 667 | | 67 | 950 |
| **other nauplii** | 67 | 611 | 2 | 126 | 167 |
| **Cladocera** | 264 | 124 | 125 | 680 | 40 |
| ***Bosmina longirostris*** | 601 | 4 | 6 | 32 | 12 |
| ***Daphnia sp.*** | 2825 | 1589 | 2 | 1709 | 2883 |
| ***Diaphanosoma sp.*** | 648 | 560 | | 885 | 1408 |
| **Rotifera** | 182 | 2676 | 28 | 36 | 10 |
| ***Asplancha sp.*** | | | 28 | 1 | |
| ***Keratella sp.*** | 1 | | 8 | 5 | 1 |

The five most numerous macroinvertebrate taxa identified during each sampling period are listed in Table 5. The amphipod genus *Hyalella*, the ostracod family cyprididae, and the ephemeropteran (mayfly) genus *Caenis* dominated the September 1997 pre-treatment samples. Copepods and *Corbicula fluminea* clams were also in the top 5 taxa. One week after the treatment, the mayflies and the ostracods were still very numerous, but the amphipods were greatly reduced in number in the samples. Higher numbers of chironomid midge larvae, *Corbicula fluminea* clams, and oligochaete worms were captured to fill out the top five positions. The increased numbers of clams and worms suggest that the October sampling may have dug deeper into the reservoir bottom sediments than earlier.

**Table 4. Mean biological metric values (coefficient of variation in %) generated for invertebrates samples collected in the littoral zone of Lake Davis. October 1997 sampling date was seven days after rotenone was applied to Lake Davis.**

| Biological Metrics | 9/26/1997 | 10/23/1997 | 7/30/1998 | 8/18/1999 |
|---|---|---|---|---|
| **Abundance** | 5077 (61) | 2891 (64) | 2947 (68) | 3094 (41) |
| **Taxa Richness** | 19 (15) | 16 (12) | 26 (14) | 21 (19) |
| **EPT Taxa** | 3.9 (27) | 2.5 (35) | 2.1 (42) | 2.6 (32) |
| **EPT Index** | 26 (47) | 23 (50) | 4 (67) | 52 (41) |
| **% Dominant Taxon** | 33 (24) | 39 (23) | 26 (32) | 47 (38) |
| **Shannon Diversity** | 2.08 (10) | 1.86 (11) | 2.47 (10) | 1.87 (23) |

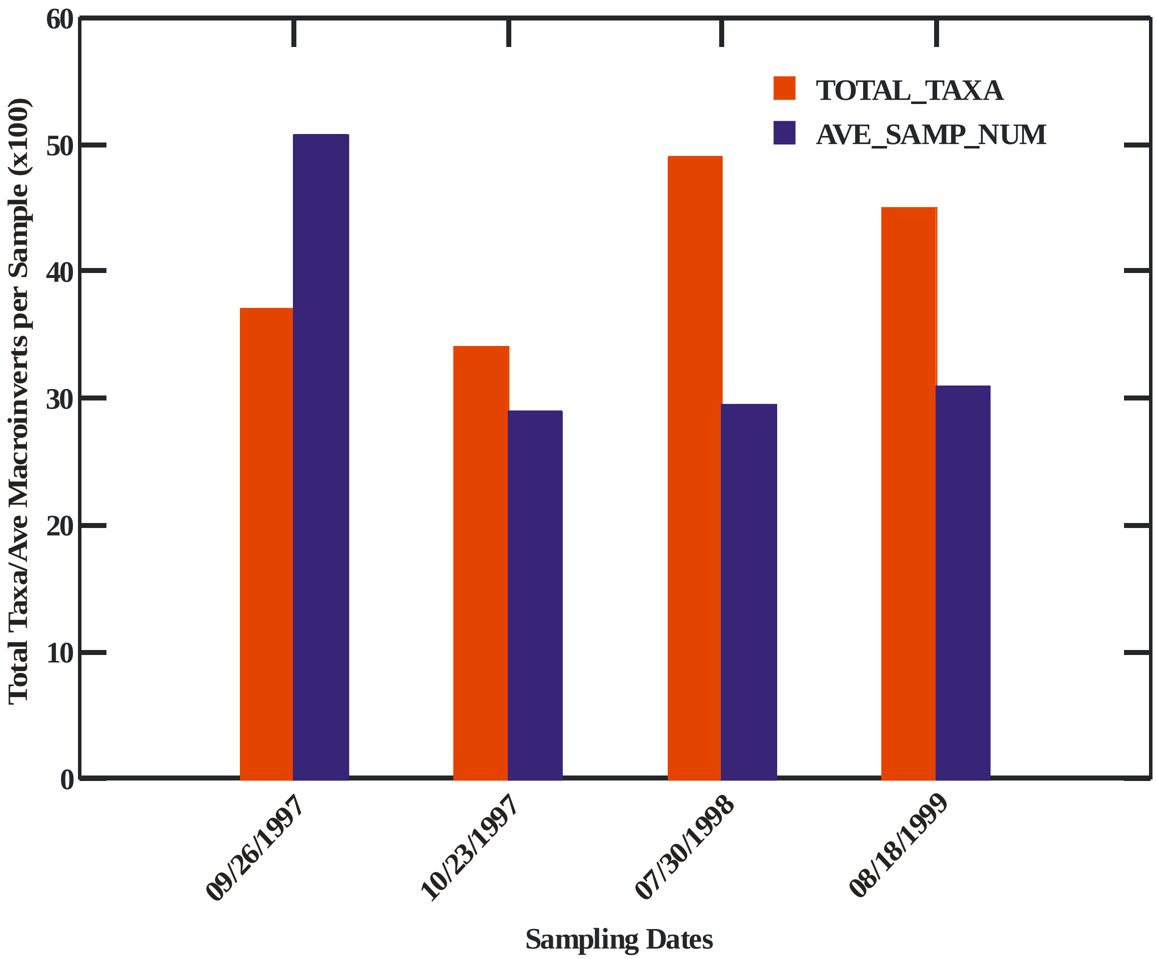


**Figure 2. Total number of littoral macroinvertebrate taxa sampled and average density of littoral macroinvertebrates in each sample from 10 coves in Lake Davis.**

The cumulative number of macroinvertebrate taxa identified from all samples during a sampling event decreased from 37 (pre-treatment) to 34 (immediately post-treatment), increased to 49 in late July, 1998, then decreased to 45 in mid August, 1999 (Table 6, Figure 2). Much of the increase of taxa numbers in the 1998 and 1999 samples can be attributed to increases in the number of Coleoptera and Hemiptera taxa. When the taxa in those two orders are removed from the cumulative total, the resulting cumulative taxa totals remained essentially the same for all sampling events (Table 6).

One taxonomic group of non-insect macroinvertebrates, the snails (Class Gastropoda), of particular importance in Lake Davis due to their regular inclusion in trout diets, decreased in abundance after the treatment along with the rest of the macroinvertebrates (Appendix B, Figure 3). Post-treatment abundance across all snail taxa in the samples was 53% of the pre-treatment level one week after treatment. But unlike most other macroinvertebrate taxa groups, the snails (as a group) recovered to near pre-treatment abundance within 9 months and reached 154% of pre-treatment abundance by the 22 month (post-treatment) samplings. The increases in snail abundance were led by the families Physidae and Planorbidae, both in the subclass Pulmonata (lunged snails). A

**Table 5. Five most numerous (shaded) littoral macroinvertebrate taxa identified during each sampling period at Lake Davis. Numbers are totals per sampling event.**

| PHYLUM ARTHROPODA | 9/26/1997 | 10/23/1997 | 7/30/1998 | 8/18/1999 |
|---|---|---|---|---|
| Class Insecta | | | | |
| Diptera | | | | |
| Chironomidae | | | | |
| Chironominae | | | | |
| Chironomini | 240 | 623 | 922 | 130 |
| Tanytarsini | 205 | 322 | 682 | 605 |
| Orthocladiinae | 196 | 179 | 740 | 607 |
| Odonata | | | | |
| Coenagrionidae | | 98 | 528 | |
| *Coenagrion/ Enallagma* | 1 | 2 | | 1 |
| Undetermined | 280 | | | 296 |
| Ephemeroptera | | | | |
| Baetidae | | | | |
| *Callibaetis sp.* | 327 | 2 | 187 | 3531 |
| Caenidae | | | | |
| *Caenis sp.* | 1787 | 2841 | 114 | 677 |
| Subphylum Crustacea | | | | |
| Class Copepoda | 537 | 25 | 950 | 290 |
| Class Malacostraca | | | | |
| Amphipoda | | | | |
| Hyalellidae | | | | |
| *Hyalella azteca* | | 190 | | |
| *Hyalella sp.* | 1096 | | 32 | 240 |
| Class Ostracoda | | | | |
| Ostracoda | | | | |
| Cyprididae | 2138 | 1950 | 1029 | 295 |
| PHYLUM MOLLUSCA | | | | |
| Class Bivalvia | | | | |
| Pelecypoda | | | | |
| Corbiculidae | | | | |
| *Corbicula fluminea* | 575 | 756 | 6 | 12 |
| PHYLUM ANNELIDA | | | | |
| Class Oligochaeta | 143 | 317 | 475 | 89 |

third Pulmonata family, Lymnaeidae, did not recover as quickly, but still reached near pre-treatment abundance by the 22 month samplings. The other subclass of snails found in the lake, Prosobranchia (gilled snails), was impacted to a greater degree by the treatment (which targets gilled organisms). The abundance of *Valvata sp.* (Family Valvatidae), the only genus of Prosobranchia found in Lake Davis, was at 57% of the pre-treatment level 1 week after treatment, then at 9% of pre-treatment abundance at the 9 month post-treatment samplings. The genus recovered to 40% of the pre-treatment abundance at the 22 month samplings.

**Table 6. Cumulative number of littoral invertebrate taxa for each sampling event, number of taxa represented by the Order Coleoptera, number of taxa represented by the Order Hemiptera and the number of taxa remaining after these two groups are removed.**

| | 9/26/1997 | 10/23/1997 | 7/30/1998 | 8/18/1999 |
|---|---|---|---|---|
| **Cumulative Taxa** | 37 | 34 | 49 | 45 |
| **Coleoptera (C) Taxa** | 2 | 1 | 12 | 9 |
| **Hemiptera (H) Taxa** | 4 | 1 | 6 | 5 |
| **Cumulative Taxa minus C and H Taxa** | 31 | 32 | 31 | 31 |

Of the taxa identified prior to treatment, 2 taxa, the genus *Mystacides* (Trichoptera) and the family Planariidae (Turbellaria), were not found in samples taken in and/or after the October 1997 sampling event (Appendix C). Fifteen taxa were identified only from samples taken after the post-treatment sampling (October 1997).

## Discussion

Rotenone blocks important biochemical pathways of cell metabolism in both fish and invertebrates (Lindahl and Oberg 1961, Oberg 1962), shutting down the ability of the organisms to take up oxygen across their gills. Different invertebrate taxa have different tolerances to rotenone. Table 7 shows lethal toxicity values for various invertebrates, including the common zooplankter *Daphnia pulex*. Toxicity values do not exist for all the invertebrates sampled from Lake Davis, but many of the taxa identified in this study are related to those listed in Table 7. For example, there is a toxicity value of 1.1 ug/L for *Daphnia pulex* and, although that particular species may not have lived in Lake Davis, there were 4 closely related taxa of daphnids that were identified in the zooplankton samples.

Rotenone concentrations in Lake Davis averaged 42 ug/L immediately following the treatment on October 17, 1997. Over the next two weeks, it gradually decreased to 10 ug/L, and within 48 days it was down to 2 ug/L. The concentration of rotenone applied to Lake Davis was high enough to be lethal to roughly half of the taxa of invertebrates listed in table 7. Yet the treatment did not immediately remove all zooplankton from the water column. There were still a few left 10 days after the treatment. Unfortunately, the sampling design did not allow for the determination of the fate of those survivors. Regardless of their fate, the zooplankton community recovered from the treatment, reaching much higher densities than were observed prior to the treatment, at a similar taxa richness. The seeds for the population recovery may have been adult survivors of the treatment, or may have come from the stress-tolerant eggs that many zooplankton produce for over-wintering and during other times of environmental stress. Whatever their origins, the zooplankton community recovered and thrived in the post-treatment reservoir. The lack of predatory fish (until re-stocking occurred) likely contributed to their success.

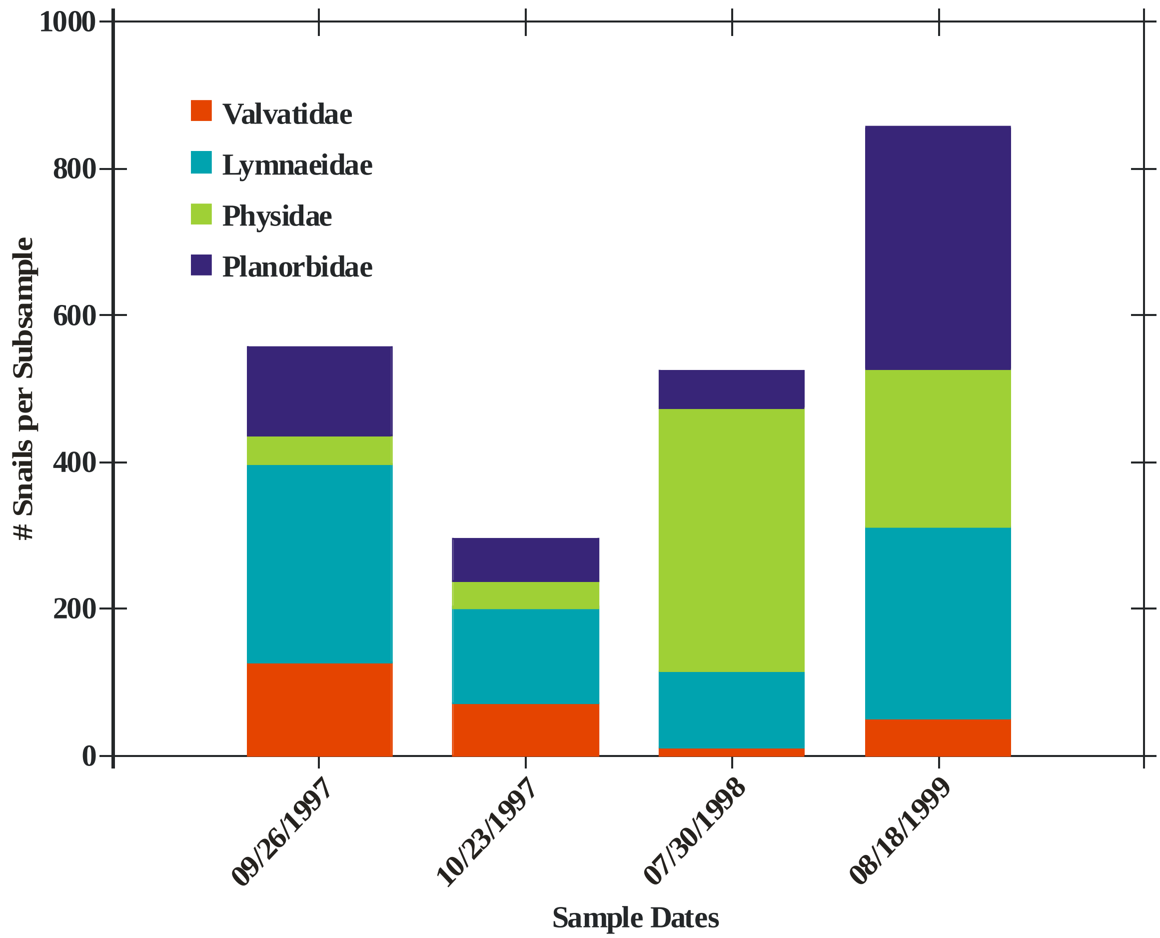


**Figure 3. Abundance of snails, by Family, identified in sub-samples, by sample date, collected from 10 coves pre- and post-treatment in Lake Davis.**

of rotenone than zooplanktors, and would be expected to survive much higher concentrations than zooplanktors for extended periods of time. Though reduced in numbers, most macroinvertebrate taxa survived the treatment and were present in the immediately post-treatment samples (October 1997). The two taxa that appear to have been removed by the treatment, the Trichoptera genus *Mystacides* and the flatworm family Planariidae, are known to be the least tolerant of the taxa identified in the littoral samples (Appendix B), and as such would be expected to be the most affected by the chemical treatment. The treatment still did not remove all of these sensitive taxa immediately. *Mystacides* were sampled in reduced numbers 10 days after the treatment, but were not identified in the following 2 sampling events. Further study will be required to determine if either of the 2 taxa eventually recovered in Lake Davis.

As for the rest of the littoral macroinvertebrate community, taxa richness increased significantly in the years following the treatment, yet the average abundance of invertebrates captured along the transects remained at a level significantly lower than that found pre-treatment, failing to demonstrate the population numbers recovery and expansion seen in the zooplankton. Some individual taxa, such as the Ephemeroptera genus *Callibaetis* and the Gastropoda families Physidae and Planorbidae, did demonstrate

**Table 7. Lethal toxicity values of rotenone (ug/L) to various aquatic invertebrates. Values were converted based on 25 ug/L rotenone in 1 mg/L Nusyn-Noxfish (Schnick 1974; Marking and Bills 1976; Chandler and Marking 1982).**

| Invertebrate Species | 24-hr $LC_{50}$ | 96-hr $LC_{50}$ |
|---|---|---|
| **Flatworm (*Catennula sp.*)** | | 68.8 |
| **Waterflea (*Daphnia pulex*)** | 1.1 | |
| **Seed Shrimp (*Cyprinopsis sp.*)** | | 13.6 |
| **Dragonfly nymph (*Macromia sp.*)** | | 44.8 |
| **Backswimmer (*Notonecta sp.*)** | | 40.0 |
| **Caddisfly larvae (*Hesperophylax sp.*)** | | 63.2 |
| **Caddisfly larvae (*Hydropsyche sp.*)** | | 100 |
| **Whriligig beetle adult (*Gyrinus sp.*)** | | 24.2 |
| **Snail (*Physa pomilia*)** | | 28.0 |
| **Snail (*Oxytrema catenaria*)** | | 160 |
| **Stonefly Nymph (*Pteronarcys sp.*)** | | 70.0 |

significantly increased abundances post-treatment, but overall the average sample abundance was 58% of the pre-treatment level in late July 1998, and 61% of the pre-treatment level in mid August 1999. The reason for this lack of recovery is unknown, and the end of the monitoring effort precluded further observation of the community dynamics.

It may be possible that a shift in the ecological balance within the macroinvertebrate community itself may have contributed to the slow population growth. Following the removal of the fish community from Lake Davis, the macroinvertebrate community experienced a dramatic increase in the number of predatory species and individuals present. Six taxa of coleoptera (beetles), at least three taxa of odonates (dragonflies), and two taxa of hemipterans (true bugs), all predaceous, all not identified in the pre-treatment samples, appeared in the reservoir after the treatment. And the numbers of odonates and hemipterans whose taxa were identified in the reservoir pre-treatment increased significantly in the later samples (Appendix C). This growth in the predator component of the macroinvertebrate community may have suppressed, at least in part, the recovery of the overall community abundance levels. The removal of the fish community, many of which target large macroinvertebrates, such as odonate nymphs, or those that swim about freely in the water column, like diving beetles and hemipterans, apparently allowed these taxa to colonize or expand their presence in Lake Davis in the absence of vertebrate predators. Their overall efficiency as predators on other macroinvertebrates may have been great enough to affect population numbers. Unfortunately this is only conjecture and the data collected for this report fails to provide any further evidence to help answer the question of why the macroinvertebrate numbers were not increasing quickly in the 2 years following the treatment.

“Biological metrics are characteristics of the biota that change in some predictable way with increased human influence” (Barbour et al. 1999). The U.S. Environmental Protection Agency (1998) lists several metrics to describe the biota of lakes and reservoirs. We chose two (abundance and taxa richness) for characterizing the zooplankton and six (abundance, taxa richness, EPT taxa, EPT index, % dominant taxon and Shannon diversity) for characterizing the invertebrates of the littoral zone. With the exception of abundance, all these metrics measure the richness, or variety, of organisms found in the reservoir. Taxa richness, % dominant taxon and Shannon diversity index considers all the organisms in the sample and EPT taxa and EPT index considers only the most sensitive types of invertebrates. Mangum and Madrigal (1999) found that EPT organisms had up to a 100% mortality rate following a rotenone treatment to the river they studied and that after five years of recovery 7% to 14% of the species did not return. In general, low values for % dominant taxon and high values for all the other metrics are indicative of healthier ecosystems that are not detrimentally influenced by humans or natural disasters. In the case of this study, we wanted to determine if the metric values returned to the pre-treatment levels by the end of the two years of monitoring.

EPT taxa and EPT index, metrics that describes the most sensitive littoral zone invertebrates, indicated a mixture of changes likely due to the rotenone treatment. There were an average of 3.9 EPT taxa in each site sample immediately before the treatment that decreased to 2.5 taxa immediately after the treatment. However, the average percent of EPT organisms in each sample exhibited little change after the rotenone treatment, indicating that the rest of the macroinvertebrate community abundance had been reduced roughly the same percent as for the EPT species as a group. The further decrease in the EPT taxa richness in the July 1998 samples, to 2.1 taxa, while of a lesser magnitude than the initial decrease, was accompanied by a significant drop in the EPT index, from 23% to 4%. The abundance of the previously numerous mayfly genus *Caenis* had dropped markedly from the October 1997 sampling to the July 1998 sampling, and, when combined with increases in the numbers of non-EPT taxa, had resulted in the considerable reduction of the EPT index. The dynamic nature of the macroinvertebrate community was again illustrated in the final sampling for this study, in September 1999. The EPT taxa metric was then at 2.6, still below the pre-treatment average of 3.9, but the EPT index had increased to 52%, twice the pre-treatment level. The mayfly genus *Calibaetis*, previously a distant second to *Caenis* in the EPT abundances pre-treatment, of which only two individuals were found in the initial post-treatment samples, had increased its presence in the samples 1000% from the pre-treatment samples to become the dominant taxon in the September 1999 samples. When the abundance of the recovering *Caenis* was added in, these 2 EPT genera accounted for 51.5 out of the EPT index of 52 in the final samples. Based on the EPT metrics, the macroinvertebrate community was still in a disturbed state two years after the treatment.

Table 8 contains a list of all the EPT organisms identified in the littoral samples. It shows that two of the four genera of caddisflies decreased in abundance following the treatment and three of the four did not fully recover by the end of the study. These changes could be a result of natural or analytical variability and may not be a product of rotenone treatment alone. It is possible that these organisms were negatively affected by rotenone application, but it is also possible that these organisms were present at the time of sampling. Because they represented such a small proportion of the invertebrate community, they might have been missed during the sampling in the field or the subsampling procedure in the laboratory. A different sampling design, with increased sampling frequency both pre- and post-treatment would have been necessary to further distinguish natural cycles of increase and decrease in taxa richness and abundance in both zooplankton and littoral macroinvertebrates from the effects of the rotenone treatment.

**Table 8. Number and (proportion of the sample) for invertebrates in the EPT metric (mayflies (Order: Ephemeroptera), stoneflies (Order: Plecoptera) and caddisflies (Order: Trichoptera)) identified from the littoral zone samples. The numbers are not totals for the reservoir population, but are based on a subsample of approximately 300 organisms from each of usually 30 samples per sampling event.**

| EPT Organisms | Sept 97 | Oct 97 | July 98 | Aug 99 |
|---|---|---|---|---|
| *Callibaetis sp.* (E) | 327 (3.8%) | 2 (<1) | 187 (2.3) | 3531 (43.3) |
| *Caenis sp.* (E) | 1787 (20.6%) | 2841 (32.6%) | 114 (1.4%) | 677 (8.3%) |
| *Agraylea sp.* (T) | 10 (0.1%) | 1 (<1%) | 5 (0.1%) | 14 (0.2%) |
| *Mystacides sp.* (T) | 32 (0.4%) | 8 (0.1%) | 0 | 0 |
| *Oecetis sp.* (T) | 37 (0.4%) | 34 (0.4%) | 3 (<1%) | 8 (0.1%) |
| *Trianenodes frontalis* (T) | 47 (0.5%) | 64 (0.7%) | 7 (0.1%) | 9 (0.1%) |
| Undetermined (T) | 6 (<1%) | 1 (<1%) | 2 (<1%) | 1 (<1%) |

In conclusion, samples taken before and after the rotenone treatment of Lake Davis indicate that the adult population of zooplankton almost entirely died off and the littoral macroinvertebrate abundance decreased to almost half of its pre-treatment level immediately following treatment; yet most of the zooplankton and macroinvertebrate community structures remained intact. Zooplankton taxa richness in the post-treatment period remained stable while the abundance increased significantly in the absence of fish. Macroinvertebrate taxa richness increased in the years after the treatment but abundance remained significantly lower through the end of this study. Sampling over the two years after the treatment failed to detect the presence of two sensitive macroinvertebrate taxa in the reservoir that had been present pre-treatment. Further study would be required to determine if the decreased macroinvertebrate abundance and missing sensitive taxa issues were resolved over time.

This study was designed to monitor zooplankton and littoral macroinvertebrate communities prior to, and for the two years after, the rotenone treatment of Lake Davis. As such, it assessed changes in these communities, primarily in abundance and basic taxa structure. It was not designed to delve into the fine details of the reservoir invertebrate populations on the species level, nor to fully distinguish natural variations in these communities from the effects solely due to the rotenone treatment. These results cannot be applied to the streams flowing into the reservoir. Separate biomonitoring studies of the streams flowing into the reservoir would be required to answer similar questions of their invertebrate communities. To address questions pertaining to the species level structure of these aquatic environments, such as about the presence of endemic or threatened/endangered species, would require, at a minimum, the more rigorous sampling and taxonomic identifications that are part of an taxa inventory project.

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